International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249–6890; ISSN(E): 2249–8001
Vol. 9, Issue 5, Oct 2019, 491–510

A REVIEW ON METALLIC DENTAL MATERIALS AND ITS FABRICATION TECHNIQUES

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ABSTRACT

Evolutions of metallic dental restorative materials are facilitated due to need in improvement in its quality such as mach in ability and aesthetics. Availability of numerous substitutes and advancement in the manufacturing technology is one of many reasons of evolution, from gold and its alloys to titanium and its alloys. Numerous innovative fabrication techniques were spotted through time from casting to additive manufacturing (AM), AM being the latest. Fatigue analysis is reviewed including finite element analysis to draw a conclusion towards the selection of suitable material and its subsequent fabrication technique.

KEYWORDS: Dental Materials, Nobel Metal Alloys, Titanium and its Alloys & Dental Prosthesis

Received: Jun 03, 2019; **Accepted:** Jun 24, 2019; **Published:** Sep 19, 2019; **Paper Id.:** IJMPERDOCT201943

Original Article

1. INTRODUCTION

Evidences of dental repairs have been found for more than 4000 years, but these early dental applications were purely based on ascetics rather than masticatory abilities. The early Phoenicians were known to use gold wires to bind teeth and then Etruscans and the romans, introduced the art of making fixed dental bridges with a strip of gold [1]. But during the middle ages these techniques became obsolete and were subsequently lost. Therefore, it cannot be said that dental restoration is a new concept; our ancestors have been practicing it since ages. With the revival of lost wax technique in the early 20th century by W. H Taggart (1907) to produce precise cast metal forms [2]. There has been a need and quest to develop new and better extra oral restorative material that can maintain the desired ascetics, restore tooth strength, longevity with being biocompatible and cost effective. The material choice for dental restoration is case specific and varies through patients. However, with the increasing wide range of available alternatives for dental repairs, it is appropriate to review the current all metal based dental materials and their fabrication techniques. The following review highlights the different metal based dental prosthesis materials like high noble metal alloys(40%>Au), noble metal alloys (20%>Au), base metal alloys (20%<Au) and titanium alloys with their subsequent fabrication techniques such as casting, electroforming, copy milling, powder metallurgy, CAD/CAM and additive manufacturing. The review includes fatigue analysis and computer aided analysis in few of the dental materials.

2. DENTAL MATERIALS

The tooth is known the strongest material in human body being stronger than any other bone in the system. It serves an integral function in our digestive system, but these teeth are subjected to failure due to health problems,

bacterial etc., thus losing its functional capability and therefore to restore the functional capability a proper substitute material is required, calling for advancement in dental materials. The substitute material must satisfy both biological and functional requirements [3, 4].

Biological requirements are that it must be non-allergic, must not cause any kind of health hazards and must be resistant to tarnish and corrosion. Functional requirements are high yield strength, transverse strength, fatigue resistant, and impact strength, modulus of elasticity, ductility resilience, toughness and hardness [5].

Each of the above requirements has been considered to satisfy specific needs that is, high yield strength and transverse strength to resist permanent deformation and transverse bending. High fatigue strength is to be resistant to cyclic loading. Impact strength is to absorb fracture energy and sudden loads. High ductility is to facilitate burnish ability and high resilience to absorb energy of elastic deformation. High toughness is to absorb energy of facture and high hardness to preserve the finished and polished surface [3-6]. All metal restorations are classified as high noble metal alloys, noble metal alloys, base metal alloys and titanium alloys [7].

2.1 High Noble Metal Alloys

Alloys containing equal or greater to 40% gold and lesser than or equal to 60% by weight of noble metal elements, they are high noble metal alloys. Gold has a good reputation in terms of bio compatibility, and it is the least reactive metal. Gold on its own is too soft and ductile to be used as a single restorative material, so it is used as an alloy injunction with other materials to improve its properties. Hardness and elasticity of gold is increased with the addition of platinum to the gold based high noble metal alloys and the same is true for the increase in the melting temperature of the alloy. Palladium can be used in place of platinum, as its servers the same purpose and is also cost-effective compare to platinum [7].

Copper is added to the alloy as a hardener making it heat treatable and to undergo age hardening. The alloy is heated between 200-450^{0}C for 15 to 30 minutes followed with quenching. This increases the hardness, proportional limit and yield strength of the alloy at the cost of its ductility [8]. The addition of different materials is done to get the required properties and the ascetics. Silver is used to offset the reddish colour of copper. While zinc is added as an oxygen scavenger that helps during the melting and casting of the alloys, iridium or ruthenium is added for grain refinement, which in turn improves the yield strength. Examples of such alloys used for all metal crown restoration for high noble metal alloys include Au-Ag-Pd, Au-Pd-Cu- Ag alloys [3].

2.2 Nobel Metal Alloys

Alloys that contain greater than or equal to 25% by weight, of noble metals are known as noble metal alloys. The less expensive palladium-based alloys were introduced in the 19th century due to hike in gold prices. The alloys are white in colour and majorly contain silver, but 25% of the alloy is palladium which provides nobility and resistance to corrosion, there is a possibility of a small quantity of gold and copper in them. Examples of such alloys, which are used for all metal crown restoration, include Ag-Pd and Ag-Pd-Au-Cu [8]. These alloys, however, have been associated with specific disadvantages. First, both silver and palladium have the affection to oxygen in molten state, thus they dissolves the free oxygen from air, resulting in porous castings. Second, low gold content in the alloys lowers the density, and thus reduces the kinetic energy of the molten metal during casting, ultimately resulting in the

poor cast ability of such alloys [8]. Also, these alloys are more prone to tarnish and corrosion when compared with gold alloys [10].

2.3 Base Metal Alloys

Base metal alloys contain less than 25% by weight; of noble metals. These alloys are generally not resistant to corrosion. So, it is imparted by adding chromium. When this alloy comes in contact with air or oxygen, forms a thin layer of chromium oxide on the surface, and thereby, preventing the diffusion of oxygen into the underlying metal surface. Nickel-Chromiun and Nickel-Chromium-Beryllium are two of the most generally utilized base metal alloys for extra-coronal single-tooth crown restoration. Beryllium is used as a grain refiner and to improve the physical properties of the alloys i. e. to increase the strength and lowers the melting point of the alloy, which helps in increasing the cast ability. Base metal alloys generally have the advantage of being lightweight with a high modulus of elasticity, which provides rigidity, even in slender segments and can be sandblasted to obtain highbond strengths with the selected resin adhesives. However, these base metals are difficult to cut, grind and polish due to their extreme hardness [10].

2.4 Titanium and its Alloys

Titanium (Ti) and its alloys have high strength to density ratio [11], which makes titanium and its alloys one of the best choices for biomedical applications [12]. Due to titanium's low electrical conductivity that contributes to the electrochemical oxidation of titanium, there is formation of a thin passive oxide layer which makes titanium biocompatible [13]. This oxide layer prevents the oxygen from reaching lower layers of the material, and thus has high corrosion resistance. This protective oxide layer remains in the human body's Ph, as the iso electric point of titanium oxide is 5-6 [14, 15]. In an aqueous environment, Ti and its oxides have a very less tendency for ion formation and low reactivity with macromolecules compared to other restorative materials [16]. Damaged hard tissue is been replaced with biomedical implants, which are made up of titanium alloys. Some examples of Ti used in biomedical applications are dental and orthopedic implants, heart valve prostheses, screws for fracture fixation, pacemakers, artificial hearts, artificial knee joints, bone plates, artificial hip joints [14] and corneal back [17]. Therefore, titanium and titanium alloys have been widely used as biomedical implant materials since the early 1970s, and implants have been used as machined and cast components. Preferred alloys for the manufacture of titanium implants are commercial pure titanium (CP-Ti) and titanium alloy Ti6Al4V (Ti-64). CP-Ti has higher corrosion resistance and is widely considered to be the most biocompatible metal [14]. Due to pioneering research by Bråne mark and colleagues, CP-Ti has been commercially available as restorative material for mucosal dental implants [18].

The physical and mechanical properties of the metals and its alloys such as high noble alloys, noble alloys, base metal alloys and titanium and its alloys used for dental restorations are compared in Tables 1- 4 [3,4].

Table 1: Physical and Mechanical Properties of Majorly used Dental Alloys

	Ti-6Al-4V (Titanium Alloy)	Au-Ag-Pd-Cu (Gold Alloy)	Co-Cr-Mo (Base Metal Alloy)
Yield Tensile Strength	1100MPa	410–984MPa	448–517MPa
Modulus of Elasticity	114GPa	81.3–123GPa	280GPa
Hardness	396HV	175.7–332HV	296HV
Compressive Yield	1070MPa		
Fracture	43MPa		

Table 2: Physical and Mechanical Properties of Some Modern High Noble and Noble Metal Dental Alloys for Full Metal Prostheses

Alloy Type	ADA Classification	Density (g/cm^3)	Yield Strength (MPa)	Hardness (VHN)	Elastic Modulus (GPa)	Percentage Elongation
1	High noble	16.6	126	85	70	51
2	High noble	19.2	146	95	50	23
	High noble	15.4	221	120	109	54
3	High noble	15.5	207/276	121/182	76	39/19
	Noble	13.2	309/648	138/225	104	28/15
	Noble	10.5	297	180	51	5-6
	Noble	10.5	248/683	145/155	55	10/8
4	High noble	14.5	350/607	165/235	88	35/4
	Noble	13.2	428/683	180/255	86	28/16
	Noble	11.3	420/530	165/220	103	10/2
	Noble	10.6	460/700	195/265	116	10/3

Table 3: Physical and Mechanical Properties of Some Noble Metal Dental Alloys

Alloy Type	Density (g/cm^3)	Yield Strength (MPa)	Hardness (VHN)	Elastic Modulus (GPa)	Percentage Elongation
Au-Pt-Ag	18.4	405/469	160/195	76	12/9
Au-Pd-Ag	16.0	434	145	100	7
Au-Pd	14.4	550	210	124	30
Pd-Au	13.9	510/572	220/224	124	25/20
Pd-Au-Ag	11.0	45	240	114	11
Pd-Ag	11.0	552	200	124	21

Table 4: Comparative Properties of High Nobel Alloys and Base Metals for Metal Ceramic Prostheses

Property	High Noble Alloys	Co-Cr	Ni-Cr-Be	Cp-Ti
Biocompatibility	Excellent	Excellent	Fair	Excellent
Density	$14g/cm^3$	$7.5g/cm^3$	$8.7g/cm^3$	$4.5g/cm^3$
Elastic Modulus	90GPa	145–220GPa	207GPa	103GPa
Sag Resistance	Poor to Excellent	Excellent	Excellent	Good
Metal Cost	High	Low	Low	Low

3. FABRICATING METHODS FOR DENTAL PROSTHESIS

3.1 Casting

Defined as a process of converting the wax pattern of the restoration into a replica or a duplicate in dental alloy, process is used to make inlays, on lays, crowns, bridges this technique was popularized by the introduction of lost wax technique by WH Taggert [7]. Steps in making cast restorations are impression, die preparation, wax pattern fabrication, spruing, investing, burnout, casting, cleaning and polishing. All these processes are explained below.

Impression technique is used to obtain a negative imprint of the teeth to form a positive reproduction by the casting method, the positive reproduction thus formed is called a die, on which inlays crowns and other restorations are made. The die halves determine the geometry and directly influences the surface quality of the final parts [19]. The materials used for dies are gypsum, amalgam, acrylic resin, epoxy resin.

Wax pattern fabrication is countering of the wax pattern into desired shape and forms any artistic effects. The carving of the wax is done at this stage as it will save time in the end, because wax is easy to carve [1]. Wax pattern

fabrication consists of 2 types i.e. Direct and indirect. When the wax is fabricated inside the mouth, it is call direct wax pattern fabrication and when fabricated on the die it's called indirect wax pattern fabrication. Part of the casting that acts as a channel for molten metal to flow into the mould cavity after the wax has been eliminated is known as sprue, if there is a direct connection between the pattern and sprue then it is called direct sprue, but if a reservoir bar is positioned between the pattern and crucible form, then the sprue is indirect [20].

Investing derives its name from the pattern being invested with a refractory material; the material is poured into the cavity in the refractory material that is the exact duplicate of the derived part. The hardness of the refractory material used is generally very high to prevent the melting and deformation of the refractory material. This method can produce products with exceptional surface qualities. The popular type of investing is paint off, hand investing, vacuum investing [21]. Elimination of extra wax on the pattern from the mould of set investment is burnout [1].

Casting requires the movement of the molten alloy into mould spaces. So, this requires 2 basic energies i.e. the heat source and the casting force. Heat source to melt the alloy, which is often, provided by directly flames or by electricity and casting force to force the alloy into the mould cavity [22]. Divesting is the removal of casting from the investment mould. After divestment, the specimen is held in sandblasting machine to clean the remaining investment from the surface. Then the casting is trimmed and polished, the sprue is sectioned off with a cutting disc and the surface of the cast is polished with suitable stones [22].

3.2 Electroforming

Electroforming is described as a highly specialized use of electro deposition for metal part manufacturing. Methodically speaking, it is the production or reproduction of an article by electrode position of metals upon a required shape or a mandrel that is subsequently separated from the deposit [22]. Due to its ability to produce shapes and design with close dimensional tolerance with an even surface which gives it good surface finish, provides the metals with superior metallurgical properties. Due to this advantage, the process of electroforming is very popular in manufacturing complicated shapes and thin films [23].

3.2.1 Basic Principle

Electroforming is theoretically a specialized form of electroplating, in which the metal is dissolved electrolytically at an anode, which results into increase of metal ions in the electrolytic solution. Usually, electrolytic solution contains a high concentration of same metallic ion that must be deposited at cathode. The increase of metallic ions in the solution facilitates the movement of these ions towards the cathode and in deposition of them on the mandrel. Unlike electroplating, in which an existing article is taken and applied with a metallic coating to provide a decorative and protective surface, electroform there is creation of metallic object against a mandrel [24].

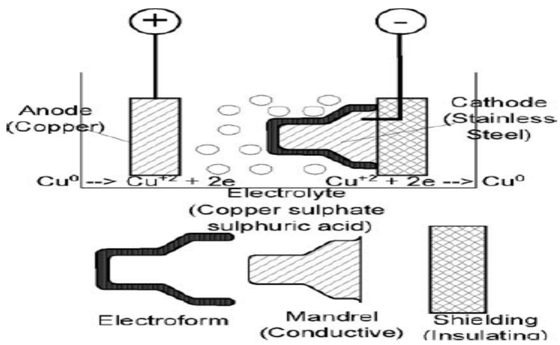

Figure 1: The Principles of Electroforming [24].

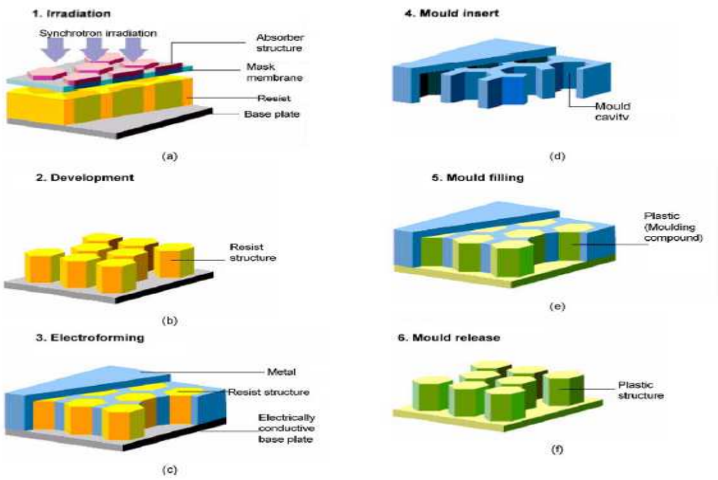

Figure 2: Basic Process of LIGA [24].

3.2.2 Lithographie Galvano for Mungab Formung (Liga)

The LIGA process had been developed by the German FZK (Research Centre Karlsruhe) in the early 1980's under the leadership of W. Her field. LIGA is a German acronym standing for the main steps of the process, i.e. Lithography, electroforming, and plastic moulding [25]. The process involves irradiation, development, electroforming, mold inserts, mold filling and mold release as few of its steps which are pictorially represented in Figure 2.

3.3 Copy Milling

Copy Milling is based on the same principle of making duplicate keys in hardware shop i.e. Pantographic principle, in which the same Mechanism of tactile model surveying and analogous milling is, used [26]. It is considered one of the very precise methods to form the crown shape.

A copy or the model of the tooth or the denture is manually fabricated in wax or other materials and then the pattern/model is placed on the pantographic machine. The tracing arm (also known as probe arm) of the machine, traces the pattern while the cutting arm which has a cutting tool attached to it follows the same path of the probe arm on the block of the restoration material. Generally, the cutting tool is made up of carbon carbide, but when the harder materials like titanium and its alloys are to mill the tool has a diamond insert to get precision cuts. The basic schematic diagram is shown in Figure 3. The final shape is usually 20-25% larger than the required shape as to allow the shrinkage of the materials during the sintering process, which is usually done to enhance the properties of the restoration material [27, 28].

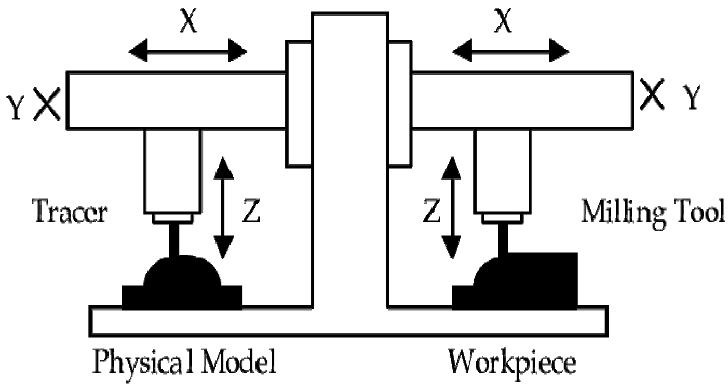

Figure 3: Schematic Diagram of Copy Milling Machine [29].

3.4 Powder Metallurgy

Powder Metallurgy (PM) is the production technique, in which, the model is made from metal powder. This is generally done by compacting the metallic powder into shape or sinter the model without compaction [30].

It became famous due to its few advantages from conventional production techniques, naming high surface area per unit volume and the ease of production of complicated shape with many voids and contours, which are very difficult to produce using the conventional method [30]. This process has high erenergy efficiency compared to conventional machining, as it requires very less post processing.

3.4.1 Process

There are three basic production processes of metal components using powder metallurgy, which are depicted in Figure 4 and explained as follows.

Pressure-Based Compaction

In this type of approach, the specimen density is established by the compaction process and then sintered to get the required strength and properties. It is one of the most cost-effective processes for mass production of a product using PM. The rigid die compaction falls under this category. For this method to work, the metal powder must be irregular and have high green strength. Extremely hard and spherical metal powders can't be compacted by this process as the strength and pressure required for compaction is extremely high. The pressure increases as the compactness increases due to hardness of this metal powder, which does not deform easily to fill the available spaces. [31]

Compaction takes place at high pressure in rigid die, usually made of cemented carbide or cold work tool steel to withstand this pressure. The green density increases as the pressure increases. Powder particles get work harden as the result of plastic deformation, and it requires higher pressure to compact more [32]. To overcome this type of problems, the warm compaction processing was developed, in which the die and the metal powder is pre-heated before compaction as it decreases the pressure required for compacting, and hence increases the green density of the material. Usually, the die and the metal powder are heated to up to a temperature of 120^{o}c (250 F) and the compaction is done in a single stroke. For ferrous metals, it gives approx. 98% of pore-free density [33].

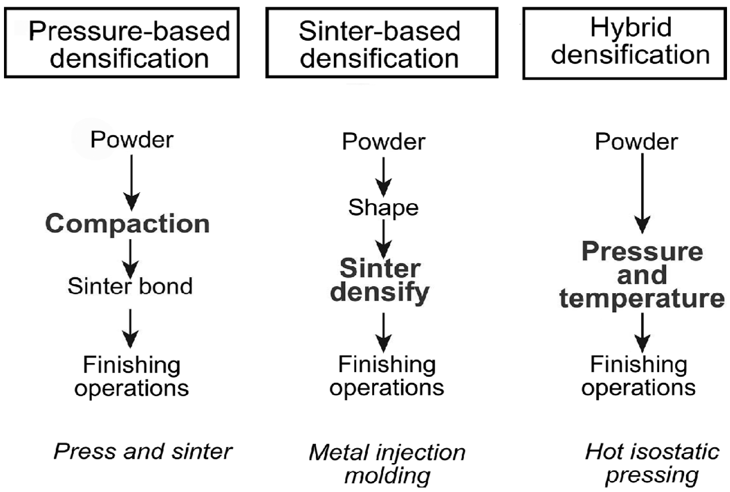

Figure 4: Three Basic Production Techniques of Metal Components [31].

Sintering Based Densification

In this process, the shape of the article/specimen is formed from metal powder in the molding operation, and then is sintered to enhance its properties. These types of process are used when the shape of the article is complex and have many voids. Usually, this is done for products that are very specific and are required at fewer quantities. There is extensive shrinkage occurring during intering but with proper estimations and tolerances, the net shape can be obtained. This process is used for materials that are difficult to machine like titanium and its alloys [34].

Hybrid Densification

For some materials, a combination of both temperature and pressure is required for compaction. As mentioned earlier, materials that are too hard and the shape of metallic powder is spherical or too reactive cannot be compressed in the rigid die. This type of materials is processed using powder extrusion or hot isostatic pressing (HIP). For reactive materials, the whole process is done in a controlled condition to prevent contamination of the materials [34].

3.5 Computer Aided Design and Computer Aided Manufacturing (Cad/Cam)

The CAD/CAM process is an indirect restoration of the dental crown and implant designed with a help of computer application and milled by a computer-controlled machine [35]. This system was developed as early as 1971, but were not widely used, mostly due to lack of accuracy in computer models and very little knowledge about materials [36]. In the late 20thcentury, the development of this process took a fast track that led to development of many softwares and machining techniques [37].

The CAD/CAM process can be divided into three steps i.e. Data collection, restoration design and machining of the material [38] which is depicted in Figure 5.

Data Collection

The dimensions, shape of the teeth and the related structure can be gathered using a conventional cast model or directly intraorally. This can be performed using an optical scanner, nuclear magnetic resonance (NMR), 3D microtomography (3D MCT) or laser technology [36,40]. Optical scanners have advantages of providing rapid data collection, while contact probe scanners tend to provide superior copy accuracy [38]. But the difference between the two is very less.

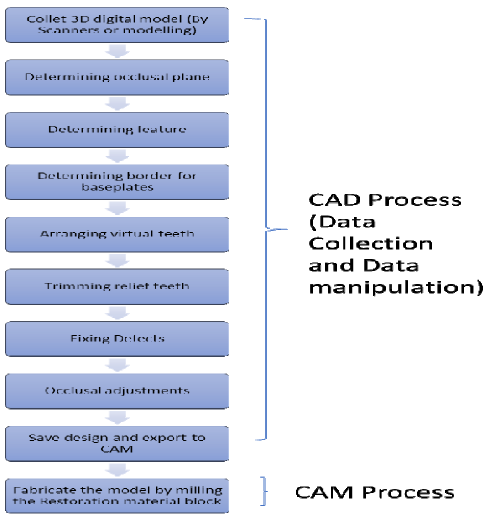

Figure 5: The Flow Chart for Designing and Fabrication of Dental Crown Via CAD/CAM Process [39]

Optical scanners can be used both intra and extra-orally. In general, their work by capturing the pattern of light and shades projected by the optical light [41]. This may have small errors in precisions due to diffusion of light [38]. This can be reduced by spraying the teeth, which have to be copied with an anti-glare solution [42].

Although 3D MCT and NMR are reordered in literature for CAD/CAM imaging, but these are rarely used as the processes have high complexity, and cost of the process is comparatively higher than the other processes.

The laseris most promptly used in the field due to the ease of the process (i.e. highly trained technician is not required, and it can be operated by the dentist) and a precise copy of the tooth can be replicated. This makes this process faster compared to others [35]. Although digital impression seems to have many advantages, still it is not applicable for all the prosthetics cases [43].

Restoration of the Design/Data Processing

From the data acquired from the previous process, the image is transferred and converted into Three-Dimensional (3D) array with the help of software. The accuracy and precision of the array or the image depend on the collection techniques [40].

This software has been developed enormously over the last 20 years, and incorporates a wide range of manipulating and unique tools for the manipulation and correction of the image of the teeth. Currently, this software used in the CAD/CAM system provides sophisticated features to detect the direct positioning of the connectors, preparation margins, etc. considering the support and aesthetics of the prosthetics [44].

Software program follows the same procedure of the indirect restoration used by a dental technician such as margin selection, placement of the die space for the cement layers and blocks out of the undercuts [45, 39]. However, the final adjustment will be determined by the dental expert as per the requirement on hand.

Computer Aided Manufacturing/Machining (CAM)

In CAD/CAM method, right after the image is finalized, the processing for machining starts with the selection of the size and position of the restoration material block in the milling machine. This is done to obtain the best results with less wastage of time and material. The milling procedures uses the tools made up of carbon carbide or have diamond tips to reduce burs and to get the accurate shape of the teeth. Coolant can be used if the restoration materials machined is of higher hardness [38].

The accuracy of the crown depends on the number of axis available in the milling machine, as the number of axis increases it increases the agility of the tool and complex shapes can be milled. It also reduces burr formation [35]. Post processing might be required for enhancing the properties of the material and to get more accurate shapes [37].

3.6 Additive Manufacturing (AM)

The alternative to subtractive manufacturing in the CAM step of the dental workflow is the additive manufacturing technique (3D printing). Additive manufacturing is defined by the American Society for Testing and Materials (ASTM) as "the process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing methodologies."[46]. Additive manufacturing has also been used as an efficient method for rapid prototyping when highly customized models are required, thus making it suitable for the highly individualized prostheses required in dentistry [47]. The Basic Steps of Additive manufacturing are shown in Figure 6.

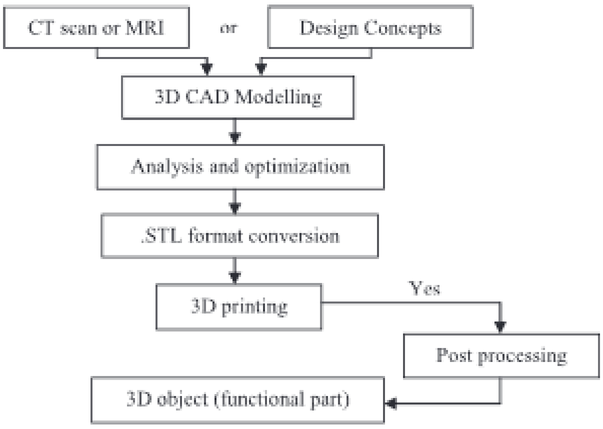

Figure 6: Schematic of 3D Printed Crown [47].

One of the AM process for metal and its alloy crown is Direct Laser Metal Sintering (DLMS), which is explained below.

3.6.1 Direct Laser Metal Sintering (DLMS)

DLMS is an additive manufacturing method, in which, a high-intensity laser beam (usually of Co_2 or Argon gas) is guided onto a metal powder bed and molten metal particles following the path given by CAD document [48]. This technology is one of the processes in the Selective Laser Sintering (SLS) process, which also lays molten metal powder, layer by layer to regenerate real 3D parts. This technology allows the fabrication of crown from a CAD file that reduces the processing time of the model [49]. The step in of DLMS Process is shown pictorially in Figure 7 and explained as follows.

The DMLS process was developed by EOS GmbH in Munich, Germany and has been commercially used since 1995 [50]. At present, many companies have begun to develop variants of the DMLS process. But in general, the DMLS process uses a high-power laser beam usually of CO_2 gas to sinter metal powder materials or molten metal for developing the specimen or the part. Argon gas is to control the atmosphere in the chamber structure due to it inert nature [51]. During the fabrication of the prototype or specimen, the building and dispenser platforms are lowered in thickness, so that the recoating blades can move without collision. The applicator moves from right to left; in this way, metal powder diffuses from the dispenser to the building area and excess metal powder falls into the collector [52]. Then, the two-dimensional cross section of the layer is accurately sintered on the metal powder particles using the high-power laser beam. The energy absorbed by the metal powder produces solidification and sintering of the solidified regions below. Within a few hours, DMLS machines can generate 3D parts with high complexity and accuracy [52]. Physical models made using DMSL can be obtained by processes such as CT or MRI [53].

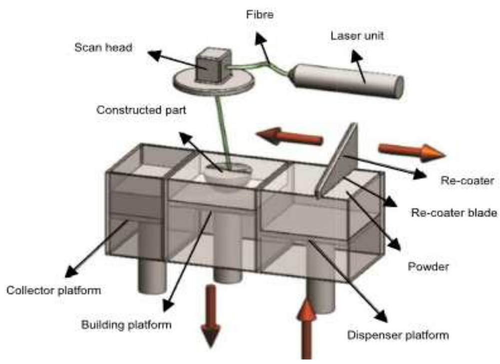

Figure 7: Pictorial Representation of the DLMS Process [52].

4 FEM ANALYSIS OF METALLIC CROWN

Finite element analysis (FEA) had been originally developed for the aircraft industry [54] and has been widely used in engineering since then, from estimating stresses in the bars to thermal stresses in reactor vessels and in structural analysis in civil engineering. In dentistry, FEA provided reliable information about tooth stress distribution as early as in the 1970s [55]. In FEA method the geometry of the structure is divided into smaller finite number of elements. The elements are of mostly in shape, which can be represented by a mathematical equation like strips, wedges and tetrahedrons etc. These elements are relatively easy to describe in terms of mechanical properties. FEA method follows approximations approach, where iterations are done to get near the exact solution, this make the properties of the element to be uniform. On this basis, the stress distribution in the FEA model of the tooth does not change gradually, but changes in steps. The Classic theory of Mechanics, along with the division of geometry into a finite number of elements creates the possibility of mathematically determining the stress in the structure, which is generated by the load applied to the same structure. Elements are connected by nodes at their corners. The displacement of a particular node due to structural loading can be calculated for each element connected to the node. The displacement is a function of the force on the element and by this; the stress and strain at a particular node can be calculated [56].

The metal and its alloys have been used for a long time in dental indirect restoration. In this review, the focus has been on two of the dental restorative metals i.e. Complete cast type III gold alloy crown (Gold) and Porcelain fused to base metal alloy (Nickel–Chromium alloy) crown (PFM) with the properties stated in Table 5. Which have been analyzed for Strength and Von Mises criteria for stress distribution using FEA Software (ANSYS version 10; ANSYS Inc., Canonsburg, PA, USA).

The study has been performed using a three-dimensional(3D) FEA[58]. The shape and dimension used to model the tooth and the crown (Table 6) was obtained from Wheeler's dental anatomy, physiology, and occlusion [59] for the dental portion of mandibular First Molar tooth restoration [57].

The 3D model consisted of 70217 nodes and 4926 elements for the model. The loading was done as for the studies conducted by Imanishi et al. [60] and Nakamura et al. [61]. Two types of loads have been applied to the model created. A distributed load of 600N have been applied in the axial (vertical) direction which simulated the maximum biting force as shown in Figure 8a. A distributed load for the normal masticatory bite force of 225N has been applied axillary and non-axially i.e. 0° to the tooth axis (vertically) (axially) [Figure 8b], 45° to the tooth axis (angularly) (nonaxially) [Figure 8c], and 90° to the tooth axis (horizontally) (nonaxially) [Figure 8d].

Table 5: Material Properties [57]

Material	Elastic Modulus(GPa)	Poisson's Ratio
Cast Gold Metal Alloy (Type 3 gold)	91	0.33
Porcelain fused to metal (Nickel-Chromium alloy)	205	0.33

Table 6: Dimension of the Crown Used in the Study [57].

Material	Occlusal Reduction (mm)	Circumferential Reduction (mm)	Crown Copying (mm)
Cast Gold Alloy	1.5	0.5	-
Porcelain fused to metal (Nickel-Chromium alloy)	2	1.5	0.3

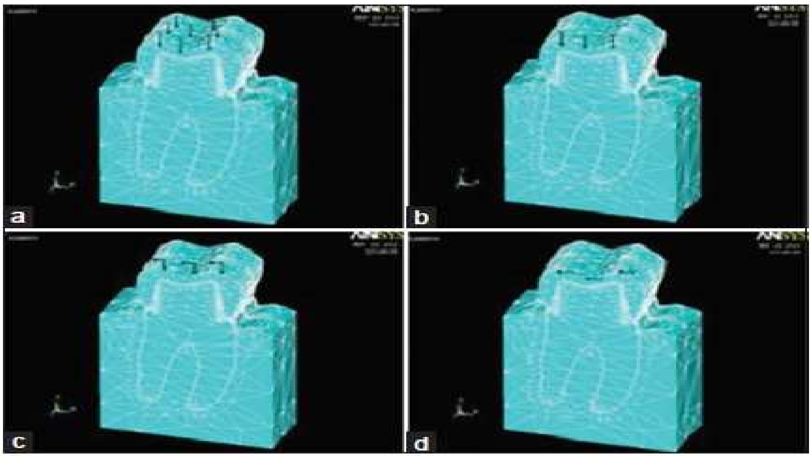

Figure 8: Loading Protocol Followed in the Study, Load Simulating (A) Maximum Bite Force of 600 N; (B) Masticatory Bite Force of 225 N At 0°; (C) Masticatory Bite Force of 225 N At 45°; (D) Masticatory Bite Force of 225 N At 90° [57].

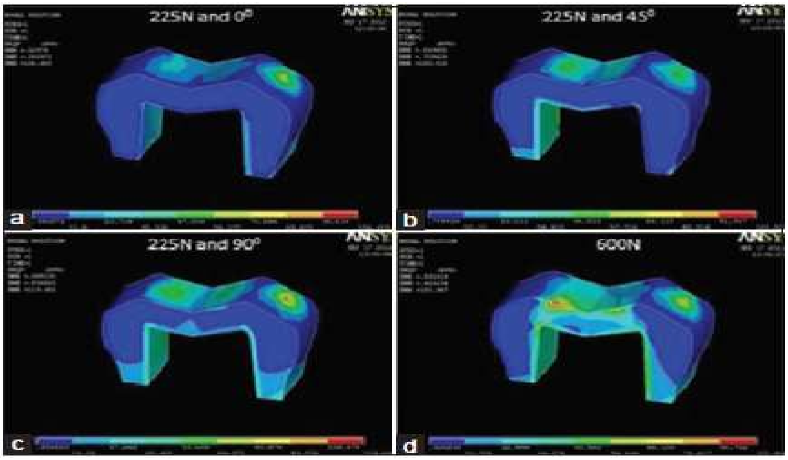

Figure 9: Von Mises Stress Distribution in Porcelain-Fused-to-Base Metal Crown at (A) Masticatory Bite Force of 225 N At 0°; (B) Masticatory Bite Force Of 225 N At 45°; (C) Masticatory Bite Force of 225 N at 90°; (D) Maximum Bite Force of 600 N [57].

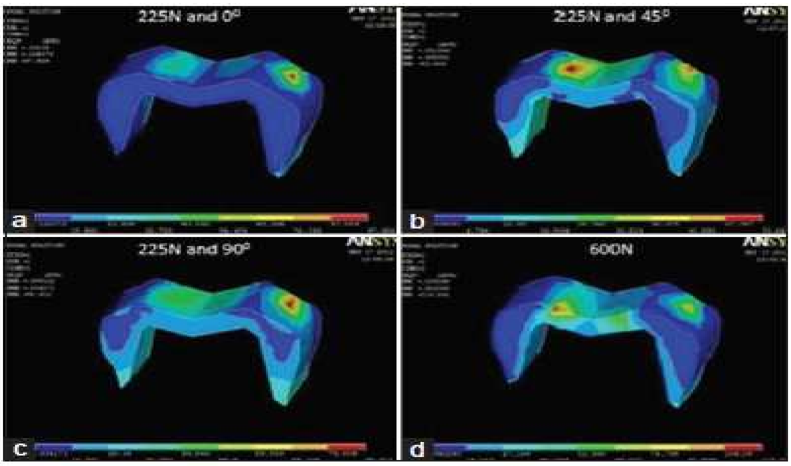

Figure 10: Von Misses Stress Distribution in Cast Gold Alloy Crown At (A) Masticatory Bite Force of 225 N At 0°; (B) Masticatory Bite Force of 225 N at 45°; (C) Masticatory Bite Force of 225 N At 90°; (D) Maximum Bite Force of 600 N [57].

Table 7: The Peak Von Misses stress Values Induced Within the Crown [57].

Crown system	600 N	225 N at 0^0	225 N at 45^o	225 N at 90^o
Cast Gold Alloy	119.241MPa	97.926MPa	53.643MPa	88.612MPa
Porcelain fused to metal	101.987MPa	106.453MPa	103.318MPa	129.846MPa

The results were determined by considering the von Mises criteria. FEA reveals the stress at each node in the model. These results are shown as stress profiles that overlap the original model. The calculated stress value data in the model is converted into a color pattern. The corresponding value of the stress (MPa) has been given in the appendix using the color code for each condition Figure 9 & 10.

The peak von Misses stress values induced in the two repair materials are then tabulated in Table 7.

Areas of maximum stress concentration were located at the loading points of the crowns for all model simulations. Moreover, increased levels of stress were also located at the cervical third of the crown when the direction of the masticatory bite force was changed from angular to the horizontal direction. This agreed with previous FEM studies.

The results support the rejection of the null hypothesis that the type of restorative material used to fabricate a posterior complete coverage crown would not affect the stress distribution pattern within the tooth restoration complex of a mandibular first molar tooth. It was observed that these materials influence the stress distribution pattern within the restoration tooth complex when subjected to different loading conditions [60, 61]. It can be seen from the results that cast gold alloy have less stress valve in all the position except at 600 N.

5. FATIGUE ANALYSIS

Most materials fail when subjected to stress or strain over a period, this process is named as "fatigue." Failures can manifest itself as sudden breakage, loss of dimension or as wear, and are often affected by surrounding and environmental factors. The stress or strain pattern can be static (maintained constant over time), dynamic (applied at some constant rate) or cyclic (stress or strain magnitude changes over time). The time elapsed before failure depends on the magnitude of the applied stress or strain and on the cyclic rate, at which; the force is applied on the body. However, for some materials, there exist lower limits of stress or strain which is general 50-60% of the yield strength below which the material can have an infinite lifetime. One can easily imagine, in the oral environment, materials used to fabricate the prosthesis are subjected to fatigue, and as a result fails or show wear [62, 63]. By conducting different test, one can evaluate specific designs, to obtain fundamental material properties, or to gather data needed to predict lifetimes [64]. Details of the Fatigue properties and the lower limit of stress or stain can be determined from the S-N diagram of the material. Dental materials like gold alloys, titanium alloys (Ti-6Al-4V) and Ag–Pd–Cu–Au–Zn alloy have been reviewed and compared for their fatigue strength. The composition of each of the materials has been tabulated in Table 8 & 9.

Table 8: Chemical Composition of Gold Alloys and Ag-Pd-Cu-Au-Zn Alloy (%Wt.) [65, 66]

Alloy	Au	Pt	Ag	Pd	Cu	Zn	Others
Gold Alloy A	68	5	6	3	15	-	3
Gold Alloy B	65	7	16	2	10	-	-
Gold Alloy C	71	2	12.3	2	12.2	-	0.5
Ag-Pd-Cu-Au-Zn	12	-	51	20	14.5	2	0.5

Table 9: Chemical Composition of Ti-6Al-4V (%Wt) [66]

Alloy	Ti	Al	V	O	Fe	C	H	N
Ti-6Al-4V	90.25–91.30	5.5–6.75	3.5–4.5	<0.2	<0.3	<0.1	<0.01	<0.05

The Gold Alloy Specimens has been tested under cyclic bending loads by a four-point supported chuck fatigue testing machine. The tests have been conducted at a frequency of 30 Hz to obtain the S-N Curve for the Gold Alloy (A, B & C) and the obtained curves are shown in Figures 11,12,13[67].

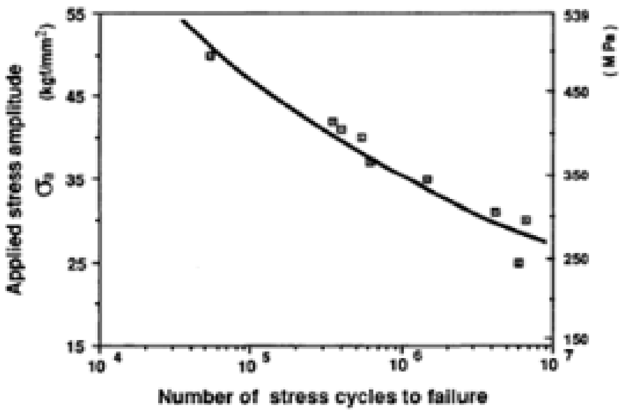

Figure 11: S-N curves of Gold Alloy A [65].

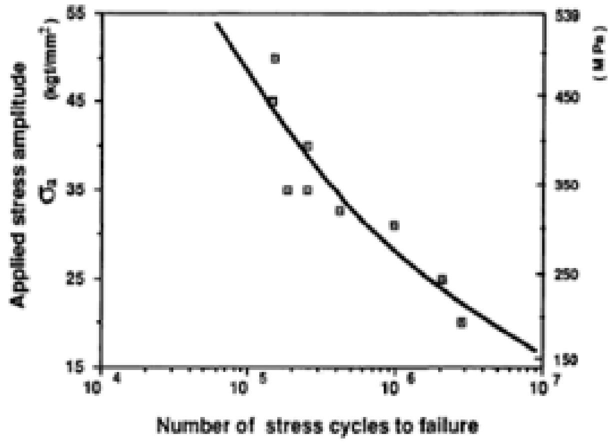

Figure 12: S-N Curve of Gold Alloy B [65].

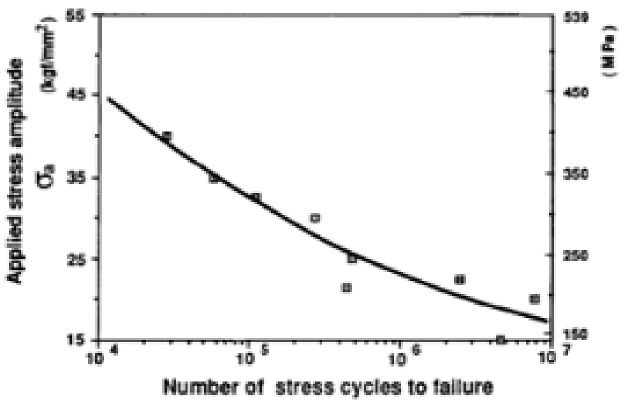

Figure 13: S-N Curve of Gold Alloy C [65].

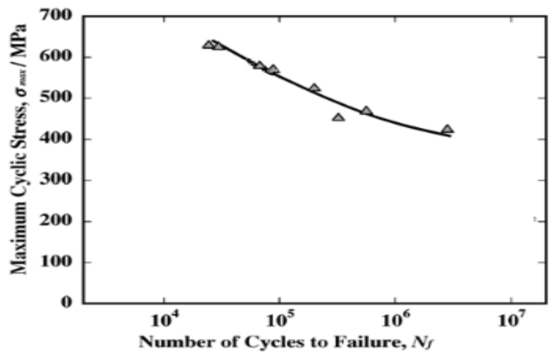

Figure 14: S-N curve of Ag–Pd–Cu–Au–Zn Alloy [66].

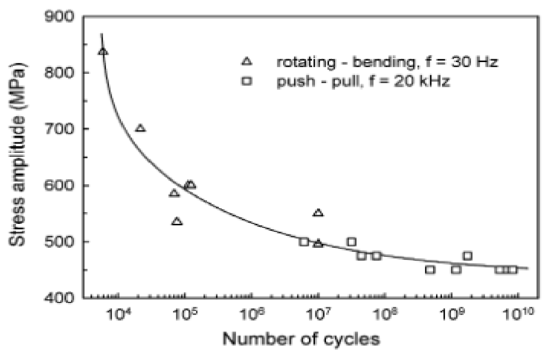

Figure 15: S-N Curve Of Ti-6Al-4V [67].

Table 10: Fatigue Strength of the Materials [65-67].

Alloy	Fatigue Strength at 10^7 Cycles (MPa)
Gold Alloy A	270
Gold Alloy B	166
Gold Alloy C	166
Ti-6Al-4V	460
Ag–Pd–Cu–Au–Zn	400

The Ag–Pd–Cu–Au–Zn alloy has undergone a fatigue test by push-pull method on the universal testing machine with a frequency of 10Hz with a sine wave. The obtained S-N curve is shown in Figure 14 [66].

The High Cycle Fatigue for the Ti-6Al-4V has been performed in the range from 10^4 to 10^7at the test frequency of 30Hzby rotating bending method. The Very High Cycle Fatigue test has been carried under fully reversed loading condition on an ultrasonic fatigue testing machine at a frequency of 20 kHz. The S-N curved obtained is as shown in Figure 15[67].

The Fatigue Strength of all the materials has been tabulated in Table 10. It can be inferred from Table 10 that the Fatigue strength of Ti-6Al-4V is more compared to Ag–Pd–Cu–Au–Zn and at last followed by gold alloys.

6. CONCLUSIONS

The material choice for dental restoration is case specific and varies through patients and their set of requirements. The desired properties are ascetics; restore tooth strength, biocompatibility, and cost-effectiveness. It is rare for a single restorative material to consist of all of these desired properties. With the advancement of fabrication technology, this gap is

getting smaller. When biocompatibility is considered noble metal and titanium and its alloys show excellent biocompatibility, wherein it is fair in base metal alloys [3]. Among the metallic dental restorative material, titanium and its alloys have the highest yield strength followed by base metal alloys and then high noble metal alloys. As most of the content in high noble metal alloys is gold and platinum, it is more expensive compared with the rest, that is then followed by titanium and its alloys. Majority of the base metal alloys are the least expensive of the bunch [4]. Fabrication of these material comes down to three factors i.e. accuracy and precision required, the time in hand and the cost considerations. The latest technology such as CAD-CAM and additive manufacturing are of the highest accuracy & precision and takes the shortest time for fabrication, but these processes are not widely used due to their associated higher cost. Thus, it can be concluded that these methods will gain traction, and will be widely used in the coming years due to the reduction in the cost associated, as there is a scope for the advancement of technology in this field.

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